(51) International Patent Classification 5 : H01J 49/34	A1	(11) International Publication Number: WO 94/01883
		(43) International Publication Date: 20 January 1994 (20.01.94)

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(54) Title: A METHOD FOR DISCRIMINATIVE PARTICLE SEPARATION
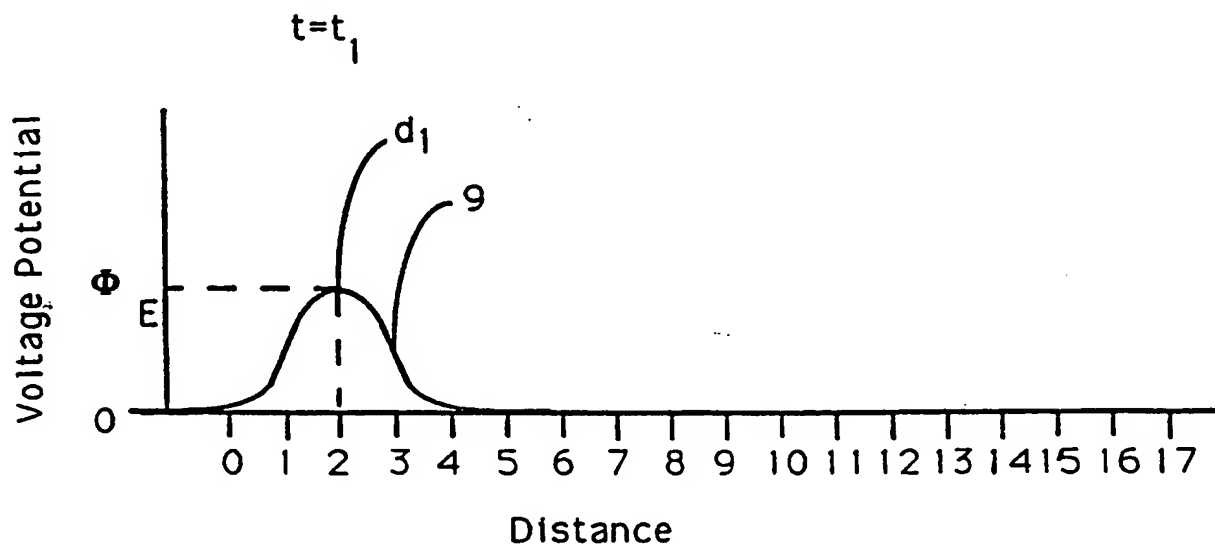
(57) Abstract

The invention is a method and means for separating ions or providing an ion beam. The invention generates ions of the isotopes to be separated, and then provides a traveling electric potential hill created by a sequential series of quasi static electric potential hills (9, 10). By regulating the velocity and potential amplitude of the traveling electric potential hill ionized isotopes are selectively positively or negatively accelerated. Since the ionized isotopes have differing final velocities, the isotopes may be collected separately or used to produce an ion beam of a selected isotope.

A METHOD FOR DISCRIMINATIVE PARTICLE SEPARATION

FIELD OF THE INVENTION

The invention relates to an improved method and apparatus for separating ions of chosen charge-to-mass ratios from other ions with a different charge-to-mass ratio. The precision obtained by the invention allows the
10   invention to be used for isotope separation. In addition, the invention may be used to provide an ion source. By contrast to other, more specialized, techniques of isotope separation the subject invention is tunable to a wide spectrum of atomic species that are of commercial interest.

There exist many areas in modern technology where
the the separation of specific isotopes of certain atomic
species is useful but where the cost of present separation
technology is prohibitively high. An example is the
5 separation of mercury isotopes. Here the intent is to
change the normal isotopic mixture of mercury to an
isotopic mixture of mercury with a higher concentration of
rare mercury isotopes to provide a fluorescent lamp which
requires less power and provides a brighter light.
10 Though it is possible in principle to accomplish such a
change through existing separator technology the cost is
too high to make this approach attractive economically.
There are also other examples where the existence of a
flexible and relatively inexpensive technique for isotope
15 separation would be valuable for commercial applications.

One of the first processes used to accomplish
such isotope separations used a mass spectrometer or mass
spectrograph. Such processes are typically expensive, and
therefore they are not used for producing large quantities
20 of separated isotopes.

Another method of separating isotopes is gaseous
diffusion. Gaseous diffusion separation provides only a
small change in concentration of the isotopes which are to
be separated. For this reason, some gaseous diffusion
25 facilities require several thousand individual stages

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cascaded together.   Since so many stages are required, for many years approximately 10% of the total electric power output of the United States was required to operate three gaseous diffusion plants.

5   Another method of separating isotopes is chemical exchange.   This process is based on the fact that if an equilibrium is established between two media, for example a substance in liquid phase and a substance in gaseous phase, the ratio between isotopes is different in one

10   media than in another.   One drawback of chemical exchange is that an isotope process using chemical exchange would be specific for a particular element.   A chemical exchange process, in general, is not be useful for separating a variety of isotopes of a variety of elements.

15   The operation of the invention can be understood in terms of an analogy, the interaction of a lighter particle with the potential field of a moving much heavier particle.   This circumstance is one of the classic problems in physics.   A familiar example is the

20   "slingshot" maneuver of a satellite directed to make a close encounter with the moon or another planet.   In such an encounter the lighter particle (the satellite) gains (or loses) energy by interacting with the potential field of the heavier particle (the moon or a planet).   This

25   process is most easily understood by conceptually going to

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the frame of reference of the potential field of the

moving heavier particle. In this frame of reference the

lighter particle approaches the potential field of the

heavier particle, is turned around, and moves away with

5   the same speed as it had before.

Viewed now from a frame at rest we see that the

lighter particle is now moving with a different velocity

from what it had before the encounter. If the encounter

is a colinear one (i.e. in 1-D), the new velocity will be

10   given by the vector equation

$$v_r = 2v_o - v_i,$$ Eq. (1)

where v_r is the velocity of the lighter particle after

reflection, v_o is the velocity of the moving potential

field, which moves with the heavier particle which

15   generates the potential field, thus the heavier particle

is also moving with a velocity v_o, and v_i is the

incident velocity of the lighter particle (all being

referred to the "laboratory" frame of reference, which is

the frame at rest). For example, if the lighter particle

20   is initially at rest in the lab frame, it will be flung

away following its encounter with the moving potential

field of the moving heavier particle at exactly twice the

velocity of that field. If the lighter particle is in

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motion parallel to the heavier particle at the time of its encounter with the potential field of the heavier particle, as indicated by equation (1), its velocity after the encounter will be $2v_o$ less its initial velocity. If overtaken by the heavier particle, its final energy will be greater than its initial energy, i.e. it will extract energy from the potential field of the heavier particle. On the other hand, if it overtakes the heavier particle from the rear it will be slowed down, i.e. it will deliver energy to the potential field of the heavier particle.

SUMMARY OF THE INVENTION

The present invention has as one of its objectives to enhance the applicability of isotope separation to a wide spectrum of atomic species, while at the same time reducing the capital and operating cost of the separator.

Another object of the invention is to provide an apparatus which is tunable to separate isotopes of a variety of elements.

Another object of the invention is to improve the electrical efficiency of the process of isotope separation, as a means of reducing its cost.

Another object of the invention is to provide an isotope separation device which utilizes "modular"

separators, so as better to accommodate to the design and fabrication of separator plants of a variety of sizes and overall capital costs

Another object of the invention is to provide ion sources within which the separation principle operates to select and extract a particular ion species, for example negatively charged ions, from a background containing electrons or other types of ions that are not of interest for the application at hand.

Additional objects, advantages and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

The invention provides a method and apparatus for changing the percentage of a first plurality of molecules having a mass $\leq M_1$ in a gas which has an initial percentage of a first plurality of molecules and an initial percentage of a second plurality of molecules of molecules having a mass $\geq M_2$ where $M_2 > M_1$. The term "molecules" in the specification and claims also

includes atoms. The invention ionizes molecules of the first plurality and the second plurality to the same charge. The invention induces among the ionized molecules at least one traveling electric potential hill wherein the amplitude and the velocity of the traveling electric potential hill is adjusted to be sufficient to provide a net positive or negative acceleration to some of the molecules of the first plurality while being insufficient provide a net positive or negative acceleration to some of the molecules of the second plurality so that the number of the first plurality of molecules which have a net acceleration divided by the total number of molecules of the gas which have a net acceleration make a percentage that is greater than the initial percentage of the first plurality of molecules. In the specification and claims, accelerating means to provide a net change in velocity which may be positive or negative, unless clearly expressed otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph of the voltage versus distance of a quasi static electric potential hill at time t_1.

Figure 2 is a graph of the voltage versus distance of a quasi static electric potential hill at time t_2.

Figure 3 is a cross-sectional view of an embodiment of the invention, which uses a plasma source.

Figure 4 is a cross-sectional view of an embodiment of the invention, which uses an ion source and

5   accelerator.

Figure 5 is a cross-sectional view of an embodiment of the invention using a mirrortron.

Figure 6 is a cross-sectional view of an embodiment of the invention using conducting rods.

DETAILED DESCRIPTIONS OF THE PREFERRED EMBODIMENTS

10   Figure 1 illustrates an electric potential hill 9 with a voltage potential amplitude of Φ_E at an instant of time t_1. At t_1 the inventive device is used to establish an electric field which causes the electric potential hill 9. At t_1 the electric potential hill 9

15   has a voltage potential near zero at a distance d=0, a voltage potential = Φ_E at d_1=2, and a voltage potential approaching zero at d=4.

Figure 2 illustrates the electric potential hill 10 imposed by the inventive device at time t_2. At t_2

20   the electric potential hill 10 has a voltage potential near zero at d=1, a voltage potential = Φ_E at d_2=3 and a voltage potential approaching zero at d=5.

Figures 1 and 2 illustrate how two quasi-static electric potential hills 9 and 10 can be made to simulate a traveling electric potential hill with a velocity v_o such that:

5                    $$v_o = (d_1 - d_2)/(t_1 - t_2)$$

The inventive apparatus continues to induce a series of localized electrical potentials which simulate a traveling electrical potential hill traveling at a velocity with a magnitude v_o.

10   At location $d=13$ an ion with a charge Ze and a mass M is located with an incident velocity v_i of approximately zero. When the traveling electrical potential hill reaches the ion, it will interact with the ion according to equation 1 with the traveling electrical

15   potential hill acting as the potential field of a moving heavier particle and the ion acting as the lighter particle. If the potential hill has a sufficiently high amplitude Φ_E, the ion will gain a reflected velocity $v_r = 2v_o$, since in this example the ion was initially at

20   rest. In that instance, the ion which had an initial kinetic energy of approximately zero, after interacting with the traveling potential hill would have a resulting kinetic energy $W_f = (1/2)Mv_o^2$ in the frame of

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reference of the traveling electric potential hill. The

amount of energy that the traveling electrical potential

hill can put into the ion from the electrical potential

hill placing an electrostatic push on the ion is

5 $W_E = Ze\Phi_E$, wherein the charge Ze of the ion is

determined by the ionic charge Z times the charge of an

electron e. If Φ_E, Z, v_o, and M are chosen so that

$(1/2)Mv_o^2 > Ze\Phi_E$, then the amplitude of the

electrical potential Φ_E is not high enough for the

10 traveling electrical potential hill to impart the kinetic

energy W_f to the ion. Therefore, instead of the ion

being reflected with a velocity with a magnitude

$v_r = 2v_o$, the ion goes over the electrical barrier,

leaving the ion unaffected by the traveling electric

15 potential hill with a final velocity which is

approximately zero.

From the above a ratio Γ is set as

$$\Gamma = (Ze\Phi_E)/((1/2)Mv_o^2) \qquad\qquad Eq.\ (2)$$

If $\Gamma < 1$, then the ion will not be reflected and will

20 have a velocity equal to approximately zero. If $\Gamma > 1$,

then the ion will be reflected and will have a reflected

velocity:

$v_r = 2v_o$ in the frame at rest.

In accordance with Equation 2, for a traveling electric potential hill with a selected amplitude Φ_o traveling at a set velocity v_o, the ratio of Z/M is what will determine whether or not Γ is greater than one, and therefore whether or not a reflected velocity with a magnitude $v_r = 2v_o$ will be imparted to the ion. Therefore in a system with a plurality of ions or charged particles at rest when a traveling electric potential hill passes through the system, for some constant $k = (2e\Phi_E)/(v_o^2)$, ions with a charge to mass ratio $Z/M > k$ will be accelerated to a velocity twice the velocity of the traveling electric potential hill while ions with a charge to mass ratio $Z/M < k$ will not be accelerated. Therefore when an traveling potential hill is applied, an ion or charged particle beam is created of ions or charged particles with a charge to mass ratio greater than k. By carefully choosing the charge to mass ratio (Z/M) and the potential Φ_E it is possible to create specialized ion beams or to separate isotopes of ions, since different isotopes of an ion could have the same charge, but would have different masses.

Consider two isotopes with masses M_1 and M_2, with M_1 being less massive than M_2. Assume also that

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both isotopes are ionized to the same charge state,
$Z=Z_1=Z_2$, and are initially "at rest" (i.e. have a low
kinetic temperature) within a low density plasma through
which a traveling potential hill is propagated. If the
5   speed of the hill and the height of the potential
(relative to its value far from the peak) are adjusted so
as to be just great enough to reflect and accelerate M_1,
then the more massive particle, M_2, will pass over the
electric potential hill as the electric potential hill
10   passes and will be left behind (provided the precision of
control over the amplitude and speed of the wave is
sufficiently good for the mass-ratio involved). In such a
situation the moving potential wave will "strip" the
plasma of those ions for which $\Gamma > 1$, and leave behind
15   those ions for which $\Gamma < 1$.

        Furthermore, since the speed of the reflected
particle will be approximately equal to $2v_o$, this fact
can be used to improve the efficiency of separation
process by collecting the selected ions at end of the
20   system in a collector cup at a potential, Φ_c, that is
chosen so that the quantity $Ze\Phi_c$ is nearly equal to
the kinetic energy of the selected ions. This technique
can also be used to discriminate against the collection of
any ions of higher charge state (but of closely similar or
25   equal mass) than that of the desired particles. Ions of

higher charge and closely similar masses will not have

sufficient energy to penetrate the end-stopping

potential. Even if their kinetic energy is close to, or

equal to, that of the desired particles, their charge is

5   too high, so that they cannot reach the collector.

Figure 3 illustrates an embodiment of the

invention, showing a cross-sectional view from the side of

a single module of the invention. Inside a vacuum chamber

11 an array of short hollow cylindrical electrodes 12 with

10   a central axis A-A are supported on insulated electrical

feed-throughs 13. At a first end of the array is located

a hollow cylindrical electrode 14 and a collector cup 15

which together comprise the collector assembly. At a

second end of the array is located a means 16 for

15   providing and maintaining a plasma along the center of the

cylindrical electrodes 12. Connected to each coil 12

through the feed-through connections 13 is an electrical

cable 19 coming from an electronic pulser chassis 17 that

generates a repetitive sequence of pulses, which when

20   applied to the electrodes 12 produces a traveling

potential hill within the cylindrical volume formed by the

interior of the aligned short cylindrical electrodes 12.

Connected to electrode 14, collector cup 15, and plasma

source 16 is power supply 18, which provides the various

25   required operating voltages to those electrodes and to the

plasma source 16.

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In operation of this embodiment, plasma source 16 generates a plasma of ions with preferably very little velocity thus having a low kinetic temperature. In an example of the operation of this embodiment the ions are ions of Mercury Hg^+. The approximate percentages of natural abundance for mercury are ^{198}Hg at 10%, ^{199}Hg at 17%, ^{200}Hg at 23%, ^{201}Hg at 13%, ^{202}Hg at 30%, and ^{204}Hg at 7%. To separate out and collect ^{198}Hg, the electronic pulse chassis 17 sequentially pulses the cylindrical electrodes 12 to create a moving electronic potential hill with a velocity of magnitude v_o with a direction along a first direction parallel to axis A-A. In this example M=198 atomic mass units, Z=1, and $e=-1.602 \times 10^{-19}$ coulombs. Therefore, $\Gamma=1$, when $2(198$ amu$)/(-1.602 \times 10^{-19}$ coulombs$)=\Phi_E/v_o^2$. By choosing an electric potential hill amplitude Φ_E and hill velocity v_o so that for M=198 amu $\Gamma>1$ and for M=199 amu $\Gamma<1$, the only singly charged mercury ions that will be accelerated by the traveling electric potential hill will be the ^{198}Hg isotopes. Mercury ions that have a +2 or greater charge will also be accelerated, since for these ions $\Gamma>1$. Therefore the traveling electric potential hill caused by the sequential pulsing of the cylindrical electrodes 12 will accelerate all singly charged ions of ^{198}Hg and all higher charged mercury

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ions to a velocity with a magnitude of approximately $2v_o$ and a direction towards the collector cup 15 in the first direction. The steady state cylinder electrode 14 is positively charged to create a potential that will turn back any ion with a mass less than 210 amu and traveling at a velocity with a magnitude $< v_o$ or having a charge equal to or greater than +2 and traveling at a velocity with a magnitude of approximately $2v_o$ or less. Since the only singly charged ions that are accelerated to a velocity of $2v_o$ are ^{198}Hg isotopes, only ^{198}Hg isotopes will pass by the steady state electrodes 14 and be collected by the collection cup 15.

In the above embodiment there is a measure of resolution, which is how precise Φ_E must be to substantially separate one isotope from another. Given two particles which are to be separated, with masses M_1 and M_2, Φ_1 and Φ_2 are defined as:

$$\Phi_1 = ((1/2)M_1 v_o^2)/Ze \quad \text{and}$$

$$\Phi_2 = ((1/2)M_2 v_o^2)/Ze.$$

Here resolution will be defined as $R = \Phi_1/\Phi_2$, where $M_1 > M_2$.

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In this embodiment $R = M_1/M_2$, since all other factors are equal and cancel out. In the above mentioned example, particle one would be ^{199}Hg and particle two would be ^{198}Hg giving a resolution of $R=199/198=1.005$.

5   This means the resolution of Φ_E needs to be about five parts in a thousand to provide the best separation between these particles. In addition higher thermal velocities tend to also diminish resolution.

Figure 4 illustrates another preferred embodiment

10   of the invention, showing a cross-sectional view from the side of a single module of the invention. A vacuum chamber 21 contains an array of short hollow cylindrical electrodes 22 supported on insulated electrical feed-throughs 23. At a first end of the array is located

15   a hollow cylindrical electrode 24 and a collector cup 25 which together comprise the collector assembly. At a second end of the array is located an ion source and accelerator 26. The ion source and accelerator 26 contains the means to provide ions of an atomic species

20   and accelerate the ions into the vacuum chamber 21. Connected to each short hollow cylindrical electrode 22 through the feed-through connections 23 is an electrical cable 20 coming from an electronic pulser chassis 27 that generates a repetitive sequence of pulses which, when

25   applied to the electrodes 22, produces a traveling

potential hill within the cylindrical volume formed by the

interior of the short electrodes 22. Connected to

electrode 24, collector cup 25, and ion source 26 is power

supply 28, which provides the various required operating

voltages to those electrodes 24,25 and to the ion source

and accelerator 26. A vacuum system 29 is provided to

maintain a vacuum in the vacuum chamber 21.

In the working of this embodiment of the

invention, the ion source and accelerator 26 provides ions

to the apparatus by accelerating the ions with an

accelerating potential V. As a result, the ions of a

charge Z enter the vacuum chamber 21 with an average

initial kinetic energy $W_i = ZeV$, where e is the charge of

an electron. The the magnitude of the average initial

velocity for each isotope v_{in} can be calculated by the

kinetic energy equation:

$$ZeV = W_i = (1/2) M_n v_{in},$$

where M_n is the mass of isotope n. The direction of the

average initial velocities is along a first direction

parallel to the axis B-B. In separating two particles

with masses M_1 and M_2, with $M_1 > M_2$, since the ions

are injected with an average initial velocity parallel to

the velocity of the traveling electric potential hill, the

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amplitude of the electric potential hill can be reduced to

and merely be in the range where Φ_E would be the

$$\Phi_E(1-v_{i1}/v_o)^2 \leq \Phi_r \leq \Phi_E(1-v_{i2}/v_o)^2,$$

amplitude of the electric potential hill if the initial

5   average velocities of the molecules were approximately

zero as in the previous embodiment. Reducing the

amplitude of the electric potential hill decreases the

demands on the inventive apparatus, allowing for a simpler

system. The resulting kinetic energy of the particles

10   accelerated by the traveling electronic potential hill is

$$W_{rn}=4W_o(1-1/2(v_{in}/v_o))^2, \text{ where}$$

$$W_o=(1/2)Mv_o^2.$$

In determining the resolution for separating two

particles with masses M_1 and M_2, with $M_1 > M_2$,

15   defining $\alpha=ZeV/((1/2)M_1v_o^2)$ and presuming that the

velocity from the thermal kinetic energy is negligible,

the resolution is:

$$R=\Phi_1/\Phi_2=(M_1/M_2)((1-\alpha^{1/2})^2/(1-((M_1/M_2)\alpha)^2)) \quad \text{Eq. (4)}$$

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When the accelerating potential V of the ion source and
accelerator 26 is zero, $\alpha=0$. In that case this
embodiment becomes like the previous embodiment and
$R=M_1/M_2$. In this embodiment $\alpha=0.80$, for example.

5   This means that the energy ZeV imparted to the particles
by the ion source and accelerator 26 is 80% of the kinetic
energy $(1/2)Mv_o^2$ imparted to the particles by a
traveling electric potential hill as described in the
previous embodiment. Using the example of particles in

10   the previous embodiment where $M_1/M_2=1.005$, $R=1.049$.
Where in the previous embodiment the resolution of Φ_E
had to be five parts in a thousand, in this embodiment the
resolution of Φ_r needs to be approximately five parts
in a hundred. This difference in resolution provides a

15   greater tolerance. This tolerance is important because an
increase in thermal energy requires a greater tolerance.
Thermal movement will diminish resolution, making the
second embodiment more desirable in some instances.

In this embodiment since the magnitudes of the

20   velocities of the particles as they are accelerated from
the ion source and accelerator 26 are less than the
magnitude of the velocity of the traveling electric
potential hill v_o, the traveling electric potential hill
overtakes the particle. Thus this is called the hill

25   overtaking mode. When pre-acceleration is used, two

distinct modes of separation may be employed in the same
type of apparatus. These are: (1) the "hill overtaking"
(H-O) mode, in which the magnitudes of the velocities of
the pre-accelerated ions is less than that of the hill,
and (2) the "particle overtaking" (P-O) mode in which the
opposite is true. The differences between these two modes
of operation appear in the details of the mass resolution
and the energy efficiency. Both modes may, however, have
the potential for better mass-resolving power and higher
efficiency than the case of no pre-acceleration as in the
first embodiment.

As the ions are continually added to the system,
and the desired isotopes are stripped from the plasma, the
remainder of the ions leak into the outer parts of the
vacuum chamber 21 around the outside of the cylindrical
electrodes 22 and are removed by the vacuum system 29.

There are also applications where it would be
desirable to create the traveling potential within a
plasma where the use of electrodes might be ineffective
because of the screening effect of the plasma on
externally applied electric fields. One technique would
be to utilize the "Mirrortron" principle (U.S. Patent
Number 4,899,084 incorporated by reference) where a
traveling electrical potential is generated by the
application, from outside the plasma, of a traveling

magnetic field. The effect of this traveling magnetic

field is to cause a relative displacement of the plasma

electrons relative to the ions, thus creating a local

region of positive potential moving through the plasma.

5   This moving potential could then either be used to "strip"

the plasma of selected ions in situ, or ion beams could be

injected into the end of the plasma to be selectively

sorted by the moving space-charge field.

        Figure 5 is an illustration of one embodiment of

10   the invention, which utilizes a Mirrortron. In this

embodiment, magnetic mirrors 40, which are magnetic coils

in a ring, are used to create dc mirror cells in a

magnetic mirror type magnetic field, which will be used to

hold a hot electron plasma. Since this requires that the

15   magnetic field created by the magnetic mirrors 40 be a

continuous magnetic field the magnetic mirrors 40 are

powered by a continuous power source 50. These magnetic

mirrors 40 may have a mirror ratio on the order of two. A

mirror ratio is defined as the ratio between the strongest

20   point of the magnetic field along the magnetic mirror axis

C-C and the weakest point of the magnetic field between

the magnetic mirrors 40 and along the axis C-C. Microwave

source 42 is positioned to create and heat a plasma of

high energy electrons and lower energy ions held in the

25   magnetic field. Since the microwave source 42

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continuously provides energy to the plasma, the microwave

source 42 is powered by a continuous power source 52.

Additional heating could be accomplished by slow adiabatic

magnetic compression of a pre-heated plasma using the

5   magnetic mirrors 40 (or additional coils) in addition to

or in place of the microwave source 42. Power source 44

adds a slowly increasing voltage to the dc component

provided by power source 50 of the magnetic mirrors 40.

The slowly increasing voltage slowly increases the

10   magnetic field of the magnetic mirrors and the magnetic

field between them, causing adiabatic compression. The

plasma electrons would be heated to high temperatures and

would typically be allowed to approach a collisional state

such that its electron distribution function would attain

15   a quasi-static loss-cone shape. The plasma density and

electron temperature would be such as to cause only a

minor perturbation of the confining fields.

        The mirrortron also includes local coils 48,

where each local coil is a magnetic coil in a ring shape.

20   The local coils 48 are positioned between the magnetic

mirrors 40 so that plasma confined by the magnetic mirrors

40 will pass through the center of the ring shaped local

coils 48.

        An ion or particle beam source and accelerator

25   46, located along the axis C-C, introduces a beam of ions

or charged particles on a path along the axis C-C of the

magnetic mirror at an average initial velocities v_{in}.

Each local coil 48 is sequentially and rapidly pulsed up

in current. The local coils 48 produce a local mirror,

5   the height of which is comparable to, or larger than, that

of the magnetic mirrors 40. As the local coil's field

increases, hot electrons begin to be expelled from the

region by the increasing field. On a sufficiently rapid

time scale, however, the plasma ions would be essentially

10   motionless, because of their heavy mass and low kinetic

temperature. At this point the plasma quasineutrality

constraint would step in; i.e., a positive potential would

arise within the plasma of just such a magnitude as to

preserve near equality between the electron and plasma ion

15   density. The resulting positive space charge, which

creates the positive potential, thereby accelerates the

positively charged ions or charged particles in the

injected beam. To selectively accelerate a specific type

of ions or charged particles, the local coils 48 are

20   pulsed sequentially to create a traveling electric

potential hill with a velocity v_o. The local coils 48

are pulsed in order at a set speed, and the power source

or switch 56 for the ion or particle beam source 46 is

governed by a timer 54 which also controls the power

25   sources or switches 58 for the local coils 48. An

electrode 60 is charged and used to turn back ions that
lack a threshold kinetic energy.

        Timer or switch 62 controls timer 54 and power
supplies 44, 50 and 52 to allow a cyclicly generated
5   adiabatically compressed plasma. A vacuum chamber 64
surrounds the magnetic mirrors 40 and local coils 48, and
a vacuum system 66 maintains the vacuum in the chamber 64
and removes the remaining ions as they leak through the
magnetic bottle created by the magnetic mirrors 40.

10   To illustrate the operation of this embodiment
and to illustrate the particle overtaking mode, this
embodiment will be described as it is used in a particle
overtaking mode. In the operation of this embodiment of
the invention, ion source and accelerator 46 provides ions
15   to the apparatus accelerated to an average initial
velocities with components along axis C-C of v_{in}. To
compare this embodiment with the previous embodiments the
ions are also ions of Mercury Hg^+. To separate out
^{204}Hg, the local coils are pulsed sequentially at a set
20   rate so that the distance Δd between adjacent local
coils 48 and the time difference Δt between the pulsing
of adjacent coils is set so that $v_0 = \Delta d / \Delta t$. In this
example M=203 atomic mass units, Z=1, and $e = -1.602 \times 10^{-19}$
coulombs. Therefore, $\Gamma = 1$, when

$$2(203 \text{ amu})/(-1.602 \text{x} 10^{-19} \text{ coulombs}) = \Phi_E/v_o^2.$$

By choosing a value Φ_E and hill velocity of magnitude v_o so that for M=203 amu $\Gamma > 1$ and for M=204 amu $\Gamma < 1$, the only singly charged mercury ions that will be

5   accelerated by the traveling electric potential hill will be the mercury isotopes with atomic masses less than 204. Mercury ions that have a +2 or greater charge will also be accelerated, since for these ions $\Gamma > 1$. The actual amplitude of the electric potential hill will be the

10   reduced potential Φ_r, since the average initial velocities are substantial, where Φ_r falls within the range

$$\Phi_E(1-v_{i204}/v_o)^2 < \Phi_r < \Phi_E(1-v_{i203}/v_o)^2.$$

In the particle overtaking mode $v_o < v_i$. Therefore the

15   particles overtake the traveling electric potential hill. Mercury ions where $\Gamma > 1$ will be decelerated according to Equation 1, thus they will experience a negative acceleration. Mercury ions where $\Gamma < 1$ will be unaffected by the traveling potential hill and will maintain a

20   velocity with a component parallel to axis C-C of approximately v_{in}. Since v_o and Φ_E are chosen so $\Gamma < 1$ only for singly charged ^{204}Hg, only ^{204}Hg will exit the separator and pass electrode 60 with an average

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velocity with a component along the axis C-C substantially
equal to or greater than v_{in}. Since all other ions will
have a velocities with components along the axis C-C much
smaller than v_{in}, the electrode 60 will turn back all
5   other ions. Only ^{204}Hg will pass through the electrode
60. This embodiment is designed with a port 63 to pass
these ions to another system.

In the case where thermal energy is not neglected
for two particles of mass M_1 and M_2, we define
10     $\varepsilon_1 = kT/ZeV$, with kT being the kinetic temperature for
particles M_1, and $\varepsilon_2 = kT/ZeV$, with kT being the
kinetic temperature for particles M_2.

$$R = (M_1/M_2)((1 - \alpha^{1/2}(1 + (1/2)\varepsilon_1)^2)/(1 - (M_1/M_2)^{1/2}\alpha^{1/2}(1 + (1/2)\varepsilon_2)^2))$$

The invention is not critically dependent on the
15   particular method used to generate a traveling potential
hill. Some of the more important parameters are: (1) that
the hill should be limited in range (i.e. it should fall
off with distance from its peak to a small fraction of its
peak value in a distance short compared to the length of
20   the separator column), and, (2) that the amplitude and
velocity of the electric potential hill should be
sufficiently constant to not compromise the degree of mass
resolution that is desired. In the specification and

claims a potential hill is defined as having a magnitude
which falls off with distance from its peak to a small
fraction of its peak value (or amplitude) in a distance
which is short compared to the length of the separator

5   column.

Because thermal energy diminishes resolution and
amplitude and velocity of the electric potential hill
cannot be kept completely constant, separation will not be
100%. In the first embodiment, instead of yielding 100%

10 ^{198}Hg, the system need only enough resolution to
increase the concentration of ^{198}Hg from 10% to 20% and
possibly slightly increasing the concentration of ^{199}Hg
from 17% to 20%. This would result in a diminished
concentration of ^{204}Hg to less than 30%. In naturally

15 occurring concentrations of mercury, 30% of the photons
generated in a mercury lamp can be self absorbed by 30% of
the mercury gas, since ^{204}Hg makes up 30% of the mercury
gas in naturally occurring concentrations. By lowering
concentrations of the highest concentration of isotopes,

20 self absorption is lowered allowing for a more energy
efficient light bulb.

Another method of practicing the invention would
be to use the embodiment illustrated in Figure 5 in the
particle overtaking mode to significantly increase the

25 concentration of ^{204}Hg to 50%, and then as the selected

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ions pass through the port 63 they pass to the embodiment

illustrated in Figure 2 with an average initial velocities

with magnitudes of approximately v_{in}. The embodiment

illustrated in Figure 4 is set to wave overtaking mode to

5   increase the concentration of ^{198}Hg to 18% and

diminishing concentrations of ^{204}Hg and ^{202}Hg to 18%.

Figure 6 illustrates another preferred embodiment

of the invention, showing a cross-sectional view from the

side of a single module of the invention. A vacuum

10   chamber 72 contains an array of conducting rods 74a-j,

76a-j supported on insulated electrical feed-throughs 78.

At a first end of the array are located a pair of parallel

plate electrodes 80 and a collector cup 82 which together

comprise the collector assembly. At a second end of the

15   array is located an ion source and accelerator 84. This

ion source and accelerator 84 contains the means to

provide ions of an atomic species and accelerate the ions

into the vacuum chamber 72. Connected to each electrode

74, 76 through the feed-through connections 78 is an

20   electrical cable 86 coming from an electronic pulser

chassis 88 that generates a repetitive sequence of pulses

which, when applied to the electrodes 74, 76 produces a

traveling potential hill within the space formed between

the electrodes 74,76. The cabling from pulser chassis 88

25   to conducting rods 74a-j is not shown for clarity. The

traveling hill is formed by first charging a first set of

electrodes 74a and 76a to a set positive charge. After

the first set of electrodes 74a, 76a begin to charge, a

second set of electrodes 74b, 76b begins to charge. After

5   the first set of electrodes 74a, 76a reaches a maximum

charge the first set of electrodes 74a, 76a begins to

discharge. During this time a third set of electrodes

74c, 76c begins to charge. The sum of the charges of the

electrodes form a traveling electric potential hill as

10   shown in Figure 1 but with an amplitude Φ_r. Connected

to the parallel plate electrodes 80, the collector cup 82,

and the ion source 84 is a power supply 90, which provides

the various required operating voltages to those

electrodes and to the ion source. A vacuum system 92 is

15   provided to maintain a vacuum in the vacuum chamber.

In the operation of this embodiment of the

invention, ion source and accelerator 84 provides ions to

the apparatus by accelerating the ions with an

accelerating potential V and injecting them into the

20   vacuum chamber with an average initial kinetic energy

$W_i = ZeV$, producing a thin plasma sheet between electrodes

74 and 76. In this example, the two isotope to be

separated are Neon 22 (^{22}Ne) and Neon 20 (^{20}Ne). For

an accelerating potential V= 600 eV, the magnitude of the

average initial velocities v_{in} can be calculated from

the equation $ZeV = W_i = (1/2)M_n v_{in}^2$. For ^{22}Ne,

$(600eV)(1.602 \times 10^{-19}) = (1/2)(22/(6.02472 \times 10^{-23}))(v_{i22})^2$.

Therefore, for ^{22}Ne $v_{i22} = 7.256 \times 10^6$ cm/s. Using the

5   same equation for Neon 20, $v_{i20} = 7.610 \times 10^6$ cm/s. The

amplitude of the traveling potential hill is set to

accelerate both isotopes. The direction of the average

initial velocities is along a first direction from the ion

source and accelerator 72 and substantially parallel to

10   axis D-D. In this example the magnitude of the velocity

of the traveling potential hill $v_o = 10^7$ cm/s. The

direction of the velocity of the traveling potential hill

is parallel to the first direction. For ^{20}Ne, we find

$W_o = 1.03605$ keV. For ^{22}Ne, $W_o = 1.13966$ keV. Using

15   the equation $W_{fn} = 4W_o(1-(1/2)(v_{in}/v_o))^2$, for

^{20}Ne, $W_{f20} = 1.590$ keV. For ^{22}Ne, $W_{f22} = 1.851$ keV.

By applying a charge on the parallel plate electrodes 80

so that singly charged particles with a final kinetic

energy less than 1.750 keV are turned back, only ^{22}Ne

20   ions will pass to the collector cup 82.

In this embodiment, pairs of conducting rods are

used as electrodes 74, 76 instead of the hollow

cylindrical electrodes. The rods have a length into and

out of the page of Figure 6. Such rods provide an even

25   potential through the thickness of a thin plasma sheet

which may have any desired length in the direction of the length of the rod.

The separation of krypton isotopes is used in another method of using the embodiment illustrated in Figure 6. Naturally occurring krypton isotopes are ^{78}Kr, ^{80}Kr, ^{82}Kr, ^{83}Kr, ^{84}Kr, and ^{86}Kr. This preferred method allows the collection of ^{80}Kr.

In this embodiment, ion source and accelerator 84 provides singly ionized krypton isotopes accelerated to 10 keV into the vacuum chamber 72. For ^{78}Kr, $v_{i78}=1.5732 \times 10^7$ cm/s. For ^{80}Kr, $v_{i80}=1.5534 \times 10^7$ cm/s. For ^{82}Kr, $v_{i82}=1.5347 \times 10^7$ cm/s. For isotopes heavier than ^{82}Kr, $v_{i82<}<1.5347 \times 10^7$ cm/s. The traveling potential hill generated by the conducting rods 74, 76, has a velocity $v_o=2 \times 10^7$ cm/s. For ^{78}Kr, $W_{o78}=16.163$ keV. When $\Gamma=1$,
$$\Phi_{En}=((1/2)M_n v_{in}^2)/Ze=W_{on}/Ze.$$
Since the minimum $\Phi_{rn}=\Phi_{En}(1-v_{in}/v_o)^2$, then the minimum $\Phi_{rn}=(W_{on}(1-v_{in}/v_o)^2)/Ze$.

Since the charge on the ions is +1, $Ze=1$. Therefore the minimum amplitude of the potential hill for accelerating singly charged ^{78}Kr ions $\Phi_{r78}=0.73606$ kV. For ^{80}Kr, $W_{o80}=16.578$ keV. The minimum amplitude of the potential hill for accelerating singly charged ^{80}Kr ions $\Phi_{r80}=0.82663$ kV. For ^{82}Kr, $W_{o82}=16.992$

keV. For isotopes heavier than ^{82}Kr, $W_{o82<}$>16.992

keV. The minimum amplitude of the potential hill for

accelerating singly charged ions Krypton isotopes of

atomic mass 80 or greater is $\Phi_{r80\leq} \geq 0.91971$ kV. In

this embodiment the amplitude of the traveling potential

hill is set as $\Phi_R=0.8500$. As a result only the ^{78}Kr

and ^{80}Kr isotopes are accelerated by the traveling

potential hill to a kinetic energy W_{fn} specified above.

The remaining isotopes ^{82}Kr, ^{83}Kr, ^{84}Kr, and ^{86}Kr

are not accelerated by the traveling potential hill and

maintain their initial kinetic energy of 10 keV.

In this example, the parallel plate electrodes 80

are charged with a potential of +15 keV. Since isotopes

with a mass equal to or greater than ^{82}Kr are

unaccelerated by the traveling potential hill, they have a

kinetic energy of 10 keV and therefore are turned back by

the +15 keV potential created by the parallel plate

electrodes 80. Since ^{78}Kr and ^{80}Kr have a final

energy greater than 15 keV, these isotopes will pass

between the parallel conducting plates 80. They will

first be negatively accelerated by the potential from the

plates and then positively accelerated back to their final

kinetic energy W_{fn} yielding a zero net acceleration from

the parallel plate electrodes 80. The collector cup 82 is

charged with a potential +24.5 keV. Since for ^{78}Kr

$W_{f78} < +24.5$ keV, ^{78}Kr isotopes will not have enough kinetic energy to reach the collector cup 82 and will not be collected at the collector cup 82. Since for ^{80}Kr $W_{f80} > +24.5$ keV, ^{80}Kr isotopes will have enough kinetic energy to reach the collector cup 82 and will be collected at the collector cup 82. By using a combination of methods described in the previous embodiments, an isotope which is neither the heaviest or lightest can be selectively collected.

The foregoing description of preferred embodiments of the invention have been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

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CLAIMS

1. A method for changing the percentage of a first plurality of molecules having a mass $\leq M_1$ in a gas which has an initial percentage of the first plurality of molecules and an initial percentage of a second plurality

5 of molecules having a mass $\geq M_2$ where $M_2 > M_1$, comprising the steps of:

ionizing molecules of the first plurality and the second plurality; and

inducing among the ionized molecules at least one

10 traveling electric potential hill with a velocity with a magnitude v_0 and a direction in a first direction wherein the amplitude Φ of the traveling electric potential hill is sufficient to provide a net acceleration to some of the first plurality of molecules and

15 insufficient to provide a net acceleration to some of the second plurality of molecules wherein the number of molecules of the first plurality which have a net acceleration divided by the total number of the first

plurality and second plurality which have a net

20   acceleration yields a percentage which is greater than the

initial percentage of the first plurality.

2.   A method as claimed in Claim 1, further

comprising the step of inducing a static electric field

along the first direction from the traveling electric

potential hill and wherein the static electric field has a

5   potential sufficient to turn back unaccelerated ionized

molecules.

3.   A method as claimed in Claim 2, further

comprising the step of collecting accelerated molecules of

the second plurality which pass through the static

electric field.

4.   A method as claimed in Claim 1, wherein the

step of ionizing molecules, comprises the steps of,

providing a gas of the first plurality and second

plurality of molecules, and generating a plasma from the

5   gas.

5.   A method as claimed in Claim 1, further

comprising the step of accelerating the first and second

plurality of ionized molecules along the first direction

before inducing the traveling electric potential hill.

6. A method as claimed in Claim 5, wherein the step of accelerating the ionized molecules of the first and second plurality accelerates the ionized molecules to average velocities with components in the first direction

5       $> 0.5v_o$.

7. A method as claimed in Claim 6, further comprising the step of inducing a static electric field along the first direction from the traveling electric potential hill wherein the step of accelerating the

5   ionized molecules accelerates the ionized molecules to average velocities with components in the first direction $> v_o$ and wherein the static electric field has a potential sufficient to turn back molecules which experience a net negative acceleration from the induced

10   electric potential hill.

8. A method as claimed in Claim 7, further comprising the step of collecting ionized molecules of the second plurality which pass through the static electric field.

9. A method as claimed in Claim 1, wherein the step of inducing at least one traveling electric potential hill, comprises a the step of generating a series of transient electrical potentials in a sequential manner along the first direction.

10. A method as claimed in Claim 9, wherein the step of generating a series of transient electrical potentials comprises the step of placing a positive charge on a series of electrodes surrounding the ionized molecules wherein the electrodes are aligned sequentially along the first direction and wherein the electrodes are sequentially pulsed along the first direction wherein the separation between an electrode and a next subsequent electrode is d and the difference in time t is the difference in time between the initiation of a pulse in the electrode and the initiation of a pulse in the next subsequent electrode wherein $d/t = v_o$.

11. A method as described in Claim 1, wherein the first plurality of ionized molecules has a first average initial velocity with a component in the first direction v_{i1} and the second plurality of ionized molecules has a second average initial velocity with a component in the first direction v_{i2}, and wherein some

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of the first plurality and second plurality of ionized

molecules have a charge of Ze, and wherein there are

values M and v_i such that $M_1 \leq M \leq M_2$

10   and $v_{i2} \leq v_i \leq v_{i1}$ and

$$(1/2)Mv_0^2(1-v_i/v_0)^2 = Ze\Phi.$$

12.   A method as claimed in Claim 11, further

comprising the step of inducing a static electric field

along the first direction from the traveling electric

potential hill and wherein the static electric field has a

5   potential greater than $(1/2)M_2v_{i2}^2/Ze$ wherein

accelerated molecules of the first plurality pass through

the static electric field and unaccelerated molecules of

the second plurality do not pass through the static

electric field, and wherein the accelerated particles of

10   the first plurality approaching the static electric field

have a velocity with a velocity component in the first

direction, wherein the velocity component is substantially

equal to v_r wherein $v_r = 2v_0 - v_{i1}$.

13.   A method as claimed in Claim 12, wherein

some of the first plurality form a third plurality of

molecules with a mass $M_3 < M_1$ which are also ionized and

accelerated, wherein the collecting of accelerated

5   molecules of some of the first plurality comprises

charging the collection means to a potential Φ_c
wherein $1/2 M_3 v_r^2 < \Phi_c / Ze < 1/2 M_1 v_r^2$.

14. A method as claimed in Claim 11, wherein
$v_o < v_{il}$ and some of the first plurality of molecules
experience a net negative acceleration from the traveling
electric potential hill, and wherein the particles of the
first plurality which experience a net negative
acceleration have a resulting velocity with a velocity
component in the first direction, wherein the velocity
component is substantially equal to v_r wherein
$v_r = 2v_o - v_{il}$, and further comprising the step of
inducing a static electric field along the first direction
from the traveling electric potential hill and wherein the
static electric field has a potential greater than
$(1/2) M_1 v_r^2 / Ze$ wherein molecules of the second
plurality pass through the static electric field and
molecules of the first plurality which experience a net
negative acceleration do not pass through the static
electric field.

15. A method for separating a first plurality of
molecules having a mass $\leq M_1$ from a second plurality of
molecules having a mass $\geq M_2$ where $M_2 > M_1$,
comprising the steps of:

5   ionizing molecules of the first plurality and the
second plurality to a charge of Ze; and
           inducing among the ionized molecules at least one
traveling electric potential hill wherein the amplitude
Φ of the traveling electric potential hill in a first
10   direction is sufficient to provide a net acceleration of
molecules of the first plurality and insufficient to
provide a net acceleration of molecules of the second
plurality.

           16. An apparatus for changing the percentage of
a first plurality of molecules having a mass $\leq M_1$ in a
gas which has an initial percentage of the first plurality
of molecules and an initial percentage of a second
5   plurality of molecules having a mass $\geq M_2$ where
$M_2 > M_1$, comprising:
           an ionized molecule region with a first end and a
second end wherein the second end is located along a first
direction from the first end;
10   means for ionizing molecules of the first
plurality and the second plurality to a charge Ze and for
providing the ionized molecules to the ionized molecule
region; and
           means for inducing in the ionized molecule region
15   at least one traveling electric potential hill wherein the

traveling potential hill has a velocity component parallel

to the first direction of v_o and an electric potential

amplitude Φ, wherein the amplitude Φ of the electric

potential hill is sufficient to provide a net acceleration

20   to some of the first plurality of molecules and

insufficient to provide a net acceleration to some of the

second plurality of molecules wherein the number of

molecules of the first plurality which have a net

acceleration divided by the total number of the first

25   plurality and second plurality which have a net

acceleration yields a percentage which is greater than the

initial percentage of the first plurality.

        17.   An apparatus as recited in Claim 16, wherein

the means for inducing at least one traveling electric

potential hill comprises a means for generating a series

of quasi static electrical potentials in a sequential

5   manner along the first direction.

        18.   An apparatus as claimed in Claim 17, further

comprising means for inducing a static electric field

along the first direction from the traveling electric

potential hill at the second end of the ionized molecule

5   region wherein the static electric field allows some of

the ionized molecules to pass through the static electric

field and prevents some of the ionized molecules from

passing through the static electric field.

19. An apparatus as claimed in Claim 18, further

comprising means for collecting ionized molecules which

pass through the static electric field, and means for

accelerating ionized molecules to an average initial

5   velocities with a component in the first direction

$>0.5v_o$ before they enter the ionized molecule region at

the first end of the ionized molecule region.

20. An apparatus as claimed in Claim 18, wherein

the means for generating a series of transient electrical

potentials in a sequential manner along the first

direction, comprises a plurality of electrodes surrounding

5   the ionized molecule region wherein the electrodes are

aligned sequentially along the first direction and a means

for sequentially pulsing the electrodes along the first

direction so that the electrodes are charged with a

positive charge and wherein the separation between an

10   electrode and a next subsequent electrode is d and the

difference in time t is the difference in time between the

initiation of a pulse in the electrode and the initiation

of a pulse in the next subsequent electrode wherein

$d/t=v_o$.

21. An apparatus as claimed in Claim 18, wherein the means for generating a series of transient electrical potentials in a sequential manner along the first direction, comprises;

5   means for generating a plasma in the area of the ionized molecules;

means for confining the plasma in the ionized molecule region;

means for heating the plasma; and

10   a plurality of ring shaped local coils surrounding plasma wherein the local coils are aligned sequentially along the first direction and a means for sequentially providing a current to the local coils along the first direction so the local coils provide a magnetic

15   field creating a positive charge in the plasma near the local coil and wherein the separation between a local coil and a next subsequent local coil is d and the difference in time t is the difference in time between the initiation of a magnetic field in the local coil and the initiation

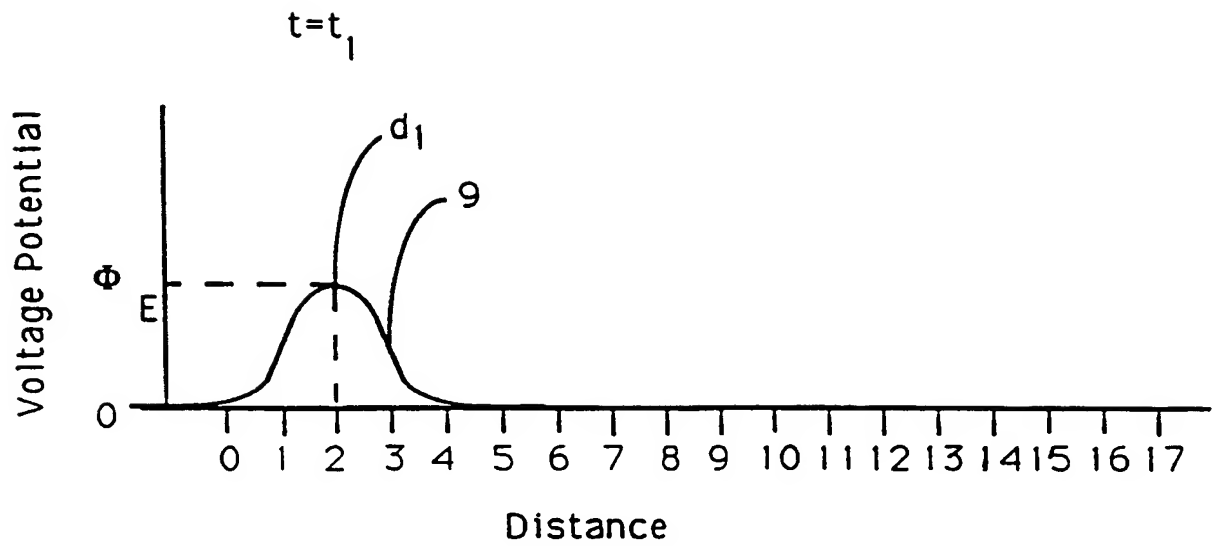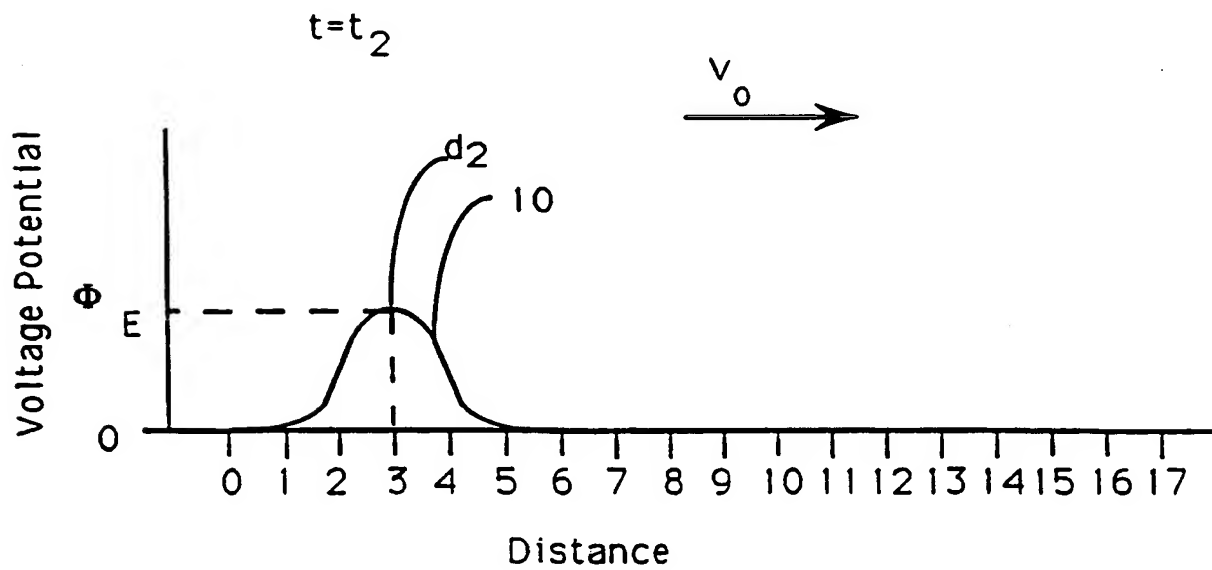20   of a magnetic field in the next subsequent local coil wherein $d/t = v_o$.
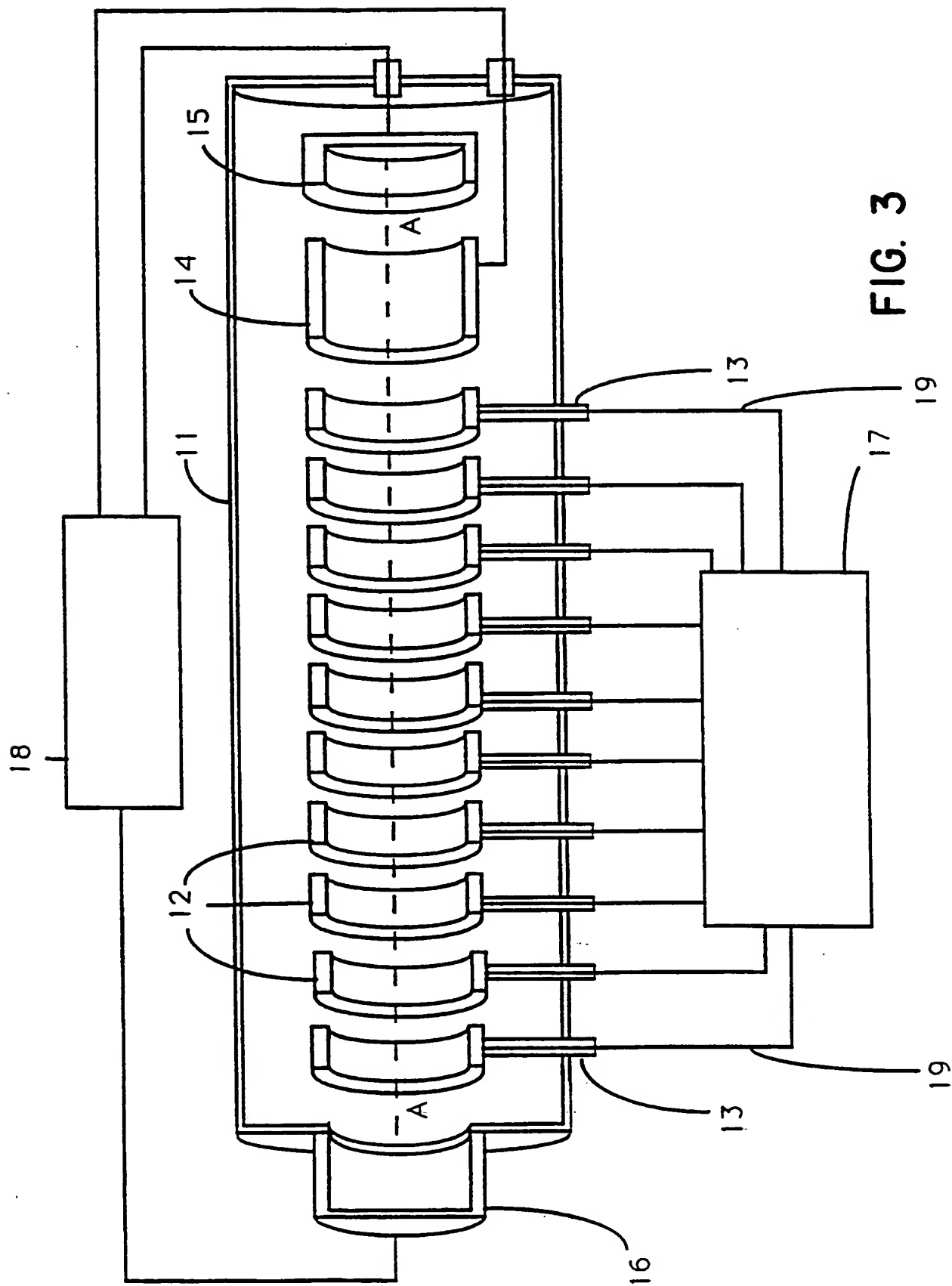
FIG. 1

FIG. 2

FIG. 3

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FIG. 4

FIG. 5

FIG. 6
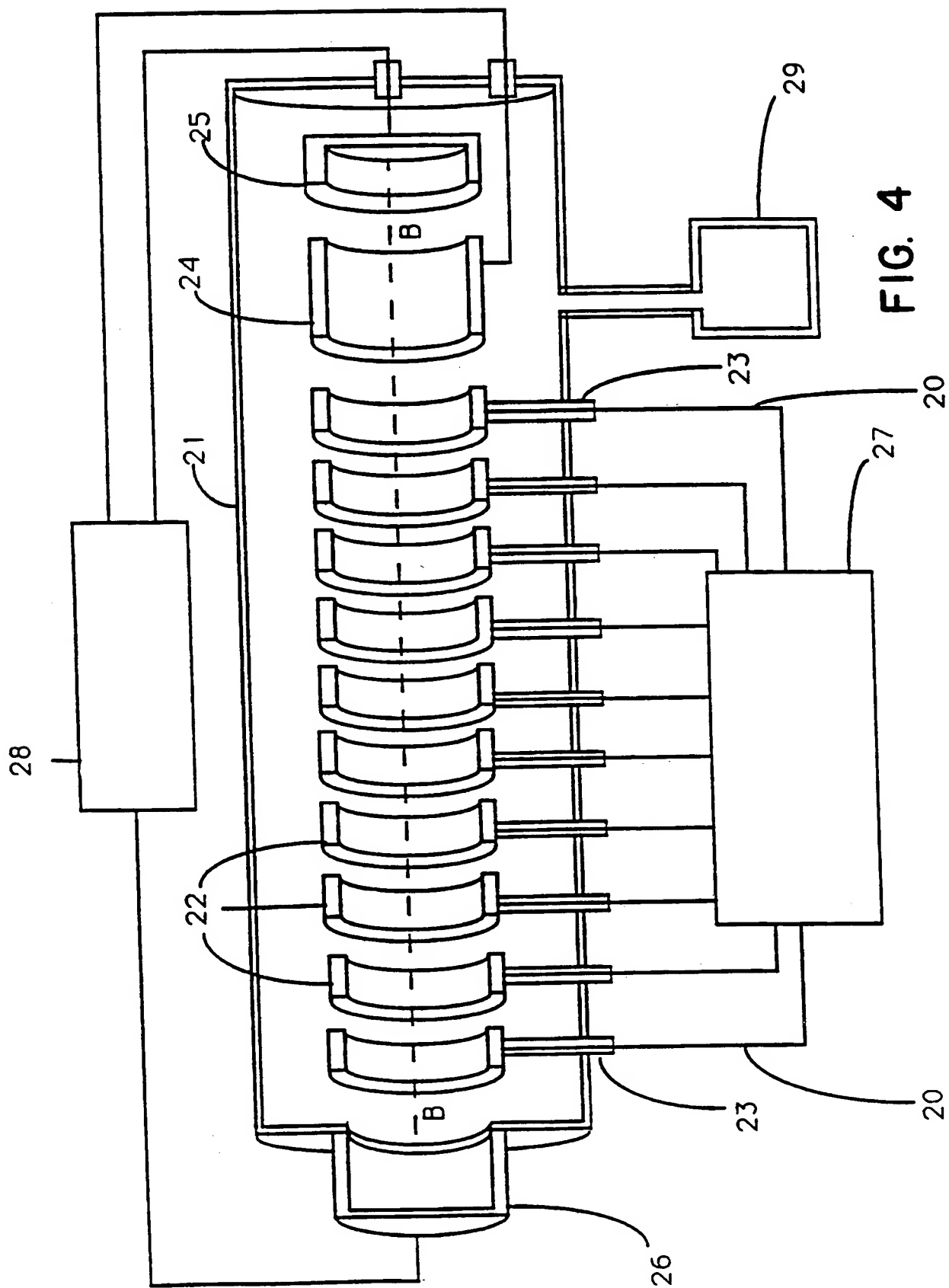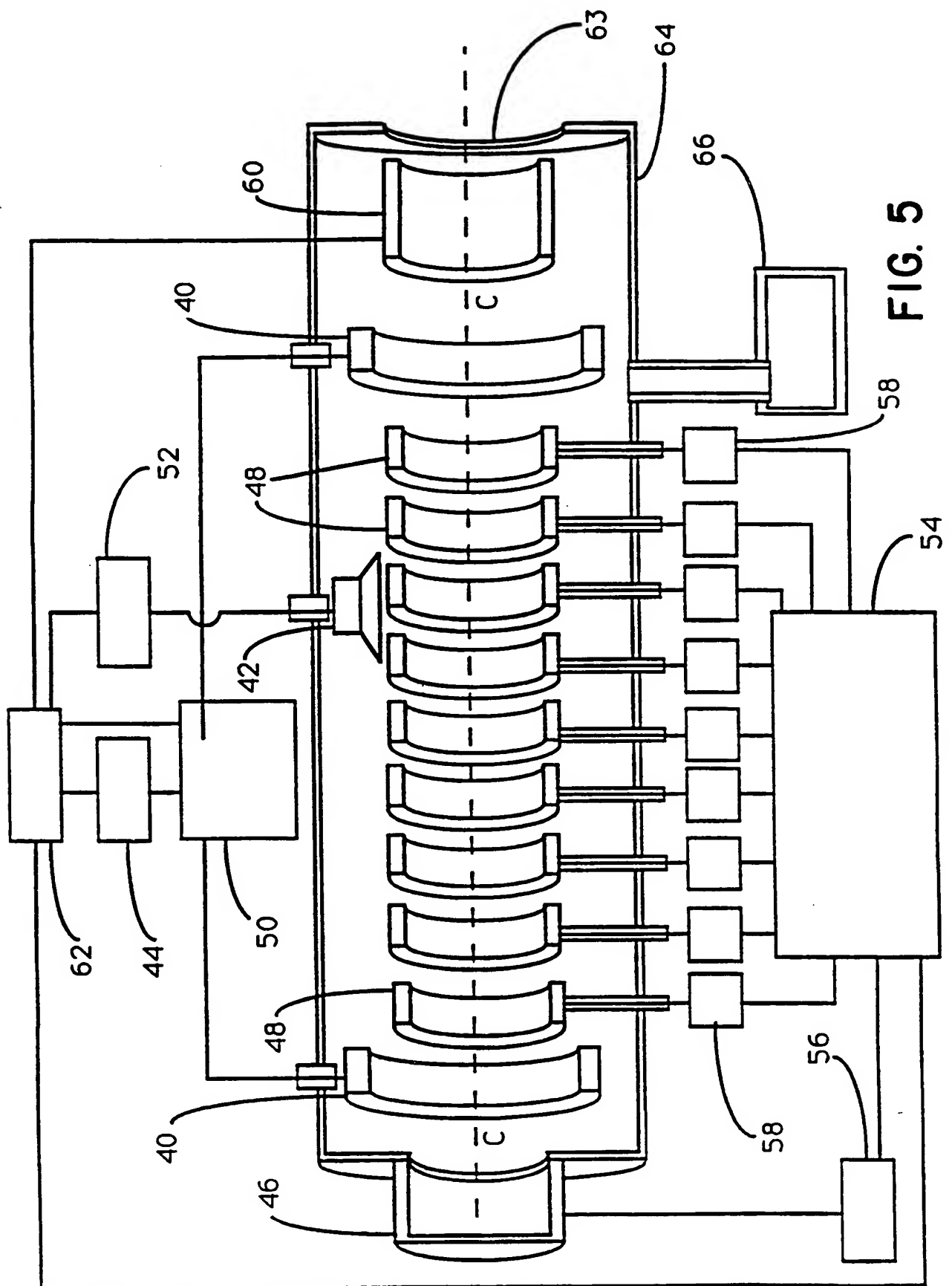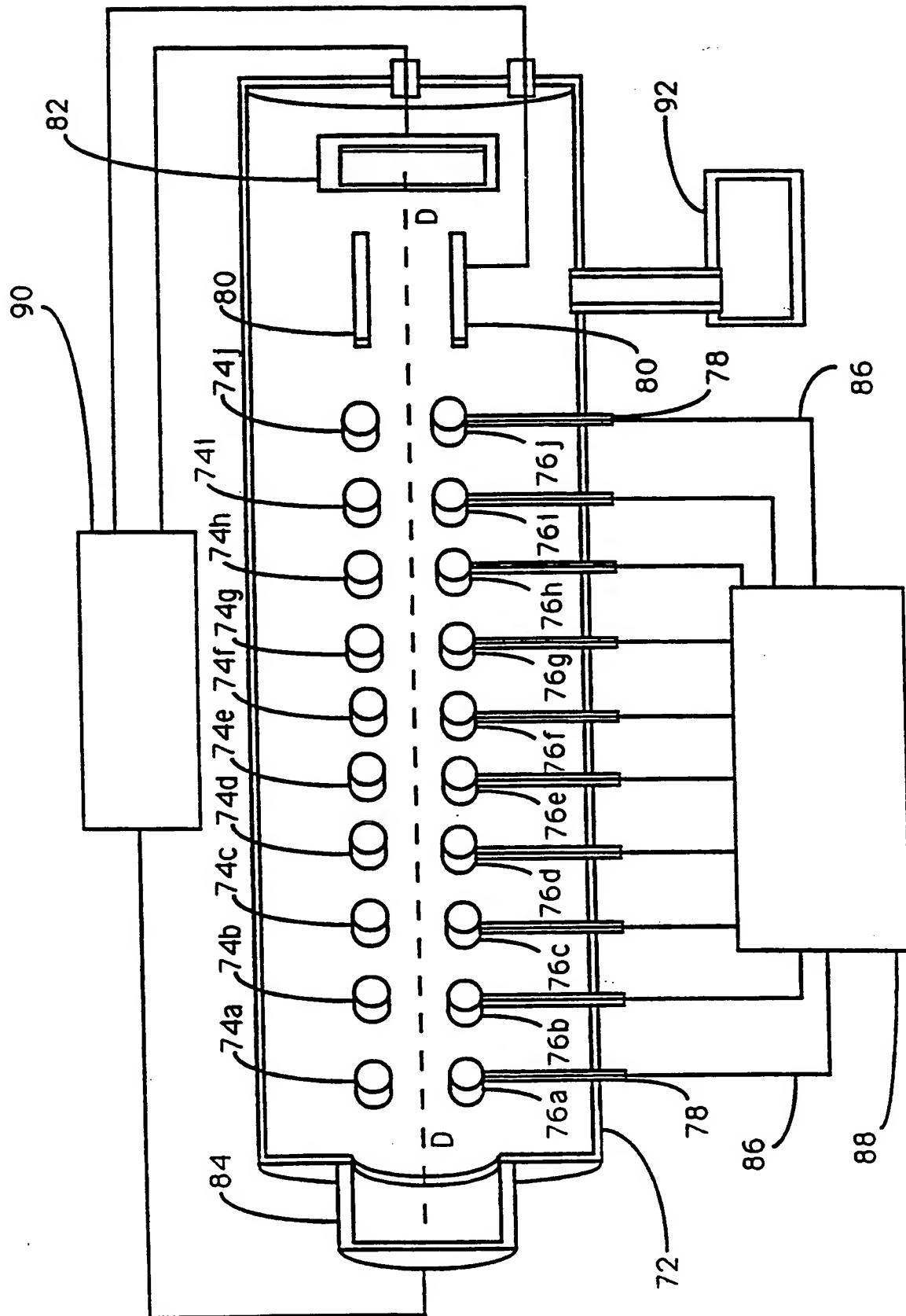
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/05438

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H01J 49/34
US CL :250/281,282,287

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 250/281,282,287

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SU,A, 368,674 (Reuta et al) 26 March 1973(abstract.)	1-6,9-11 15-18,and 20
A	US,A, 5,140,158 (Post) 18 August 1992 whole document.	1-21

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 AUGUST 1992	15 OCT 1992

Name and mailing address of the ISA/ Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer JACK BERMAN
Facsimile No. NOT APPLICABLE	Telephone No. (703) 308-4849

Form PCT/ISA/210 (second sheet)(July 1992)*

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 19
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

   It is unclear how there can be an "ionized molecule region at the first and of the ionized molecule region." This appears to be a mistake. The intended meaning is unclear.

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any addtional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention frist mentioned in the claims; it is covered by claims Nos.:

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1))(July 1992)*